E.R.D.E. 8/R/61 ~~CONFIDENTIAL~~ COPY No. 19 8

~~DISCREET~~

UNCLASSIFIED

Decl OADR

MINISTRY OF AVIATION

EXCLUDED FROM AUTOMATIC REGRADING; DOD DIR 5200.10 DOES NOT APPLY

(EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT, G.B.)

3 (REPORT No. 8/R/61) C

4 (Plastic Propellants: Aluminized Compositions) 4

5 (B.H. Newman and G.J. Spickernell)

1. THIS INFORMATION IS DISCLOSED ONLY FOR OFFICIAL USE BY THE RECIPIENT GOVERNMENT AND SUCH OF ITS CONTRACTORS, UNDER SEAL OF SECRECY, AS MAY BE ENGAGED ON A DEFENCE PROJECT. DISCLOSURE TO ANY OTHER GOVERNMENT OR RELEASE TO THE PRESS OR IN ANY OTHER WAY WOULD BE A BREACH OF THESE CONDITIONS.

2. THE INFORMATION SHOULD BE SAFEGUARDED UNDER RULES DESIGNED TO GIVE THE SAME STANDARD OF SECURITY AS THAT MAINTAINED BY HER MAJESTY'S GOVERNMENT IN THE UNITED KINGDOM.

3. THE RECIPIENT IS WARNED THAT INFORMATION CONTAINED IN THIS DOCUMENT MAY BE SUBJECT TO PRIVATELY-OWNED RIGHTS.

6 (25 mar)

INV. 90

EXCLUDED FROM AUTOMATIC REGRADING DOD DIR 5200.10 DOES NOT APPLY

(b)

C 91383

UNCLASSIFIED

~~CONFIDENTIAL~~

~~DISCREET~~

SPIA

AUG 3 1961

RECEIVED

Waltham Abbey, Essex.

Reg #25369

E.I.D.
Printing Section

MINISTRY OF AVIATION

EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT

REPORT NO. 8/R/61

Plastic Propellants: Aluminized Compositions

by

B.H. Newman and G.J. Spickernell

Approved: G.H.S. Young
G.H.S. YOUNG
S.P.R. I.

Approved for
Circulation: C.H. Johnson
C.H. JOHNSON
DIRECTOR

25th March 1961

WALTHAM ABBEY
ESSEX

CONTENTS

Reference: WAC/128/06

1. SUMMARY

The addition of aluminium to plastic propellants has resulted in a marked improvement in performance over the whole range of burning rates, 0.1 to 1.65 inch/sec. (at 1000 p.s.i.). In particular, high measured specific impulses (at least 245 lb.sec/lb) and high thrust efficiencies have been obtained with propellants burning at rates above 0.6 inch/sec. at 1000 p.s.i. and containing up to 18 per cent aluminium. Lower burning rates have been achieved by replacing oxidizer by ammonium picrate, but this was accompanied by a reduction in measured impulse and thrust efficiency.

The thrust efficiency of aluminized propellants is influenced by the three parameters: matrix energy (the energy of the binder/oxidizer part of the propellant) the propellant burning rate and the rocket motor size. The thrust efficiency of the fast-burning, high-matrix-energy propellant, is probably unaffected by motor size until more than 20 per cent aluminium is present. The aluminium particle size has no effect on combustion efficiency although it affects burning rate, pressure dependence and temperature coefficient of burning rate.

The addition of aluminium to plastic propellant has presented no additional hazard or new manufacturing problem, and the chemical stability has been unaffected.

2. INTRODUCTION

2.1 Previous Studies on Ballistics of Plastic Propellant

The wide range of burning rates available with the plastic propellant system has been described in previous reports (1, 2, 3). A paper presented at the 15th J.A.N.A.F. Solid Propellant Meeting 1959 (3), reviewed the whole field and included some measured specific impulse data for aluminized propellants assessed in 5-inch-diameter, star-centred motors.

The present report is concerned mainly with the performance of aluminized plastic propellants and is intended to be read in conjunction with the corresponding report on aluminized polyurethane propellants (4).

2.2 Scope of Investigation

This Report covers three years work in the development of high-performance aluminized plastic propellants. The highest performance systems, containing no ammonium picrate, are necessarily of rather high burning rate; slower burning aluminized propellants containing ammonium picrate have also been studied.

The inclusion of atomized aluminium powder has caused no difficulties in the processing of plastic propellant; Rotter impact tests indicate that the presence of aluminium has not increased the sensitiveness of plastic propellants.

2.3 Theoretical Performance Calculations

The reasons for adding aluminium to propellants to increase performance have been discussed in some detail by Newman and Peers (4).

/Figure 1 .....

Figure 1 shows calculated specific impulse figures for most of the aluminized plastic propellant compositions investigated in this work; these figures were calculated on the Mercury computer at R.A.E., Farnborough, by methods agreed between R.P.E., Westcott and E.R.D.E.

3. PROPELLANT PREPARATION

3.1 Method of Propellant Preparation

No additional equipment is required for the production of aluminized plastic propellants; the 5000 g. batches for K-round evaluation were manufactured in a sigma-blade Winkworth incorporator, whilst the 100 kg. batches for 5-inch motor assessment were made in Baker Perkins double-knaben-bladed 'Imperial' incorporators, which are identical with those installed at R.O.F. Bridgwater.

In view of the extreme friction sensitiveness of dry mixtures of ammonium perchlorate and aluminium, a premix is made of aluminium and binder in a separate incorporator.

The process temperatures of 70° - 80°C are the same as for non-aluminized compositions.

3.2 Types of Aluminium Powder and Effect on Processability

Two types of aluminium powder are commercially available: atomized or blown, and flake. The atomized material consists of irregular particles, roughly spherical in shape, whilst the flake is in the form of very thin flat plates coated with a layer of an anti-caking/anti-oxidizing compound such as stearic acid.

In general, the atomized grades are coarser, and of higher purity, than the flake grades. The specific surfaces of atomized samples received at E.R.D.E. lie in the range, 1000 to 15,000 cm^2/cm^3 and their purity is 99.5 per cent or better. The specific surfaces of flake grades varied from 15,000 to 90,000 cm^2/cm^3 and purity was seldom above 98 per cent because of the coating material.

The aluminium particle size had no effect on the specific impulse, so that an atomized grade which had no deleterious effect on rheological properties (Northern Aluminium Co. 120/dust grade, of specific surface, 3,500 cm^2/cm^3) was used in most compositions. Although aluminium can be incorporated in plastic propellant in any concentration without affecting chemical stability, there is a rheological limit to the amount of flake aluminium which can be used; the thin plates of this powder increase inter-particle friction, making the propellant harder and more difficult to process. For large scale processing the maximum concentration of flake aluminium appears to be about 6 per cent.

Small amounts of flake aluminium have been used in conjunction with atomized aluminium to stiffen certain compositions; the flake aluminium also increases the burning rate and decreases the temperature coefficient more than the atomized material (see Section 5.4).

/4. .....

4. BALLISTIC ASSESSMENT

Burning rates and pressure dependence were determined by firing K-rounds over a range of restriction ratios to cover the pressure range of interest (usually 500 to 1700 p.s.i.). Temperature coefficients of burning rate at constant restriction ratio were determined by firing rounds at -40°C and $+60^{\circ}$C.

Most of the performances reported here were measured in K-rounds fired at 1000 p.s.i. with carbon insert nozzles of 30° cone angle and 7:1 expansion ratio. The nozzle inlet radius was at least twice the throat diameter used.

A considerable number of 5-inch diameter motors were also fired with similar type of venturi though in all cases the impulse was either lower than or, at the best, equal to, the K-round figure. As discussed previously (4) this is thought to be due to the sliver loss associated with the 5-inch motor.

The K-round and 5-inch motor charge shapes are illustrated in Figure 2; the charge weights are approximately 0.75 and 20.0 lb respectively.

The strand burner was used only for ballistic control of batch production.

5. BALLISTIC RESULTS FOR ALUMINIZED COMPOSITIONS NOT CONTAINING AMMONIUM PICRATE

5.1 Effect of Aluminium Concentration at the 11 per cent Binder Level

Table 1 (p. 4) gives ballistic results for a series of compositions, 89 per cent loaded with ammonium perchlorate and atomized aluminium powder (specific surface 3500 cm^2/cm^3). The binder system was 10 parts polyisobutene and 1 part S.101 surface active agent (40 parts ethyl oleate, 30 parts penta-erythritol dioleate, 30 parts sodium di(2-ethylhexyl) sulphosuccinate). The initial specific surface of the oxidizer was 2000 cm^2/cm^3.

From thermochemical considerations, the composition containing 25 per cent aluminium should give the highest performance (see Figure 1). However, the plot of aluminium content against measured performance (Figure 3) shows the optimum content to be 14 per cent in K-rounds, with a sharp fall off in efficiency beyond 18 per cent.

The figures obtained from the 5-inch motor firings do not show such a fall; in fact the measured performance is relatively unaffected by aluminium content. The actual figures are much lower because of the sliver loss and on this account no efficiency figure has been quoted. The 5-inch motor results indicate that motor size has an effect on thrust efficiency at high aluminium contents.

The burning rate of this basic series of compositions can be increased by the use of catalysts and/or finer oxidizer as described in later sections. Only slight reductions in rate are achieved by the use of coarse oxidizer and slower burning rates are obtained by the replacement of oxidizer with ammonium picrate.

The addition of aluminium increases the pressure dependence of burning rate from 0.48 to 0.6 ± 0.03, which is comparable with that of a practicable, stable burning, non-aluminized propellant containing titanium dioxide. The temperature coefficient of burning rate, at constant restriction ratio, remains about 0.16 per cent/deg. F.

/TABLE 1 .....

TABLE 1

Composition No.	% Al	K-Round Ballistics					5 inch Motor Ballistics
		r_b at 1000 p.s.i.	Pressure Exponent	Temperature Coefficient of Burning Rate *	I_{sp} Measured at 1000 p.s.i.	I_{sp} † Efficiency %	I_{sp} Measured at 1000 p.s.i.
E.3090	0	0.701	0.48	0.16	237	94.2	-
E.3319	5	0.698	0.62	0.15	243	94.4	-
E.3318	10	0.650	0.60	0.16	246	94.1	238
E.3600	14	0.62	0.60	0.17	247	93.3	238
E.3569	18	0.588	0.60	0.15	245	91.1	239
E.3315	25	0.535	0.57	0.20	234	87.8	236

*The temperature coefficient of burning rate is at constant restriction ratio.

†The I_{sp} efficiency is the measured impulse at 1000 p.s.i. expressed as a percentage of the calculated figure at 1000 p.s.i.

/5.2 .....

5.2 Effect of Catalysts on the Ballistics of Aluminized Propellants

Of the many burning rate catalysts previously investigated in plastic propellants (2), copper chromate was again found to be the most effective. Its effect on the performance of aluminized propellants was studied in some detail; increase of burning rate at a given energy level was expected to improve the measured performance because of the reduced heat loss consequent on shorter burning time. It was also possible that increase in burning rate would reduce the tendency of molten aluminium to agglomerate on the burning surface and also that the copper chromate, in catalysing the oxidation of carbon monoxide, might provide a more readily reduced atmosphere for subsequent aluminium combustion.

Manganese carbonate has been claimed as an aluminium combustion catalyst by Phillips Petroleum Co. (5) and was compared with copper chromate.

Ballistic data obtained from K-round firings are given in Table 2 (p. 6). All compositions contain 10 per cent polyisobutene and 1 per cent S.101. Initial specific surface of the ammonium perchlorate was 2000 cm^2/cm^3.

The relationships between aluminium content and measured specific impulse and also thrust efficiency for the 'copper chromate series' are illustrated in Figure 4, for ease of comparison with the corresponding results for the non-catalysed series in Figure 3.

The thrust efficiency has been raised appreciably by the presence of the copper catalyst at both low and high aluminium levels; however, the maximum efficiency has been moved from the 14 per cent aluminium level to 5 per cent and there is a sharp drop in efficiency between 22 and 25 per cent aluminium.

The presence of the copper chromate has made all burning rates at 1000 p.s.i. about 1 inch/sec. With increasing aluminium content, the pressure dependence and temperature coefficient of burning rate are reduced considerably in comparison with the corresponding figures for the non-catalysed series (Table 1).

The manganese carbonate had little effect on burning rate, but improved the thrust efficiency of the non-aluminized composition to the very high value of 96.8 per cent.

5.3 Effect of Burning Rate on Measured Performance

As pointed out in the previous section (5.2), the increase in measured performance by the addition of copper chromate may have been due to one, or all, of the following factors: the increased burning rate, per se; the reduced heat loss; or catalytic activity of the additive.

A similar increase in burning rate was obtained by the use of fine oxidizer alone and a further increase was effected by the addition of 1 per cent copper chromate. Because of the high burning rate of the propellant containing both the finest oxidizer and catalyst, and throat diameter limitations with the K-round, the comparison of performance had to be made at a chamber pressure of 1500 p.s.i. Table 3 (p. 7) shows effect of burning rate on the 14 per cent aluminized composition which had given the optimum performance in Section 5.1.

/TABLE 2 .....

TABLE 2

Composition No.	NH_4ClO_4, %	Al, %	Catalyst and %	K-Round Ballistics				
				r_b at 1000 p.s.i., inch/sec.	Pressure Exponent	Temperature Coefficient %/deg.F	I_{sp} Measured at 1000 p.s.i.	Efficiency, %
E.3678	88	-	Copper Chromate 1	1.0	0.51	0.13	240.5	96.2
E.3759	86	2	" "	1.14	-	-	241.5	95.4
E.3742	83	5	" "	1.06	-	-	246	96.1
E.3384	78	10	" "	1.01	0.39	0.13	245	94.1
E.3749	73	15	" "	1.04	-	-	245.5	93.0
E.3750	68	20	" "	0.97	-	-	246	92.6
E.3760	66	22	" "	0.951	-	-	245	92.2
E.3573	63	25	" "	0.909	0.29	0.06	238	89.7
E.3679	88	-	Manganese Carbonate 1	0.66	0.56	0.18	242	96.8
E.3686	78	10	" "	0.665	0.50	0.18	244.5	93.9
E.3681	63	25	" "	0.52	0.51	0.15	236.5	89.1

/TABLE 3 .....

TABLE 3

Composition No.	Initial S_o of NH_4ClO_4, cm^2/cm^3	% NH_4ClO_4	% Copper Chromate	K-Round Ballistics				
				r_b at 1500 p.s.i., inch/sec.	Pressure Exponent	Temperature Coefficient, %/deg.F.	Measured I_{sp} at 1500 p.s.i.	Efficiency,† %
E.3600/1	2000	75	-	0.795	0.59	0.24	249	91.7
E.3600/2	5000	75	-	0.970	0.66	0.22	251	92.4
E.3600/3	8000	75	-	1.21	0.62	0.21	250.5	92.2
E.3712/1	2000	74	1	1.24	0.39	0.18	251.5	92.9
E.3712/2	5000	74	1	1.41	0.44	0.12	252.2	93.2
E.3712/3	8000	74	1	1.65	0.47	0.11	252.5	93.3

† Corrected for non-optimum expansion.

All compositions contain 14 per cent aluminium, 10 per cent polyisobutene, and 1 per cent S.101.

/A .....

A slight increase in performance is indicated as the burning rate is increased but it is not possible to say whether the catalyst has had an effect, per se. The lower thrust efficiency compared with that determined at 1000 p.s.i. may be due to nozzle design.

The investigation was repeated at the 0 and 25 per cent aluminium levels; it was felt that any effect on performance (thrust efficiency) due to increased burning rate or catalyst activity would be more noticeable in a composition of relatively low efficiency such as that containing 25 per cent aluminium. In this case, owing to the lower burning rates the performance was measured at 1000 p.s.i. The comparison is made in Table 4 (p. 9).

In this series the increase in burning rate has an obvious effect on thrust efficiency, apparently irrespective of whether the increase is caused by fine oxidizer or burning rate catalyst.

If the increase in performance was due entirely to reduced heat losses, there should have been a similar improvement in performance of the 14 per cent aluminized composition (Table 3) as the rate was increased. That this was not the case indicates that thrust efficiency can be improved markedly by burning rate increase only in cases of relatively low thrust efficiency. The effect of burning rate on impulse for the propellants described in Tables 3 and 4 is shown in Figure 5.

Further study of the ballistic parameters quoted in Tables 3 and 4 confirms previous experience that copper chromate causes a considerable reduction in temperature coefficient of burning rate, whilst fine oxidizer has the reverse effect.

5.4 Effect of Aluminium Particle Size on Performance

All the propellants described in previous sections contained atomized aluminium of 3500 cm^2/cm^3 approximate specific surface (Northern Aluminium Co. grade 120/dust).

In order to determine the effect of aluminium particle size, the four undermentioned grades were compared in propellant composition E.3348 (10 per cent aluminium, 77 per cent ammonium perchlorate, 12 per cent binder and 1 per cent surface active agent). The binder content of this composition was 12 per cent to allow the incorporation of 10 per cent flake aluminium powder.

The ballistic results are given in Table 5 (p. 10).

/TABLE 4 .....

TABLE 4

Composition No.	Initial S_o of NH_4ClO_4, cm^2/cm^3	% NH_4ClO_4	% Al.	% Copper Chromate	K-Round Ballistics				
					r_b at 1000 p.s.i., inch/sec.	Pressure Exponent	Temperature Coefficient, %/deg.F	Measured I_{sp} at 1000 p.s.i.	Efficiency, %
E.3090	2000	89	-	-	0.701	0.48	0.16	237	94.4
E.3090	8000	89	-	-	1.127	0.70	-	241	96.0
E.3678	2000	88	-	1	1.00	0.51	0.13	241	96.4
E.3315	2000	64	25	-	0.535	0.57	0.20	234	88.2
E.3315	8000	64	25	-	0.88	0.76	0.25	239	89.7
E.3573/1	2000	63	25	1	0.909	0.29	0.06	238	89.7
E.3573/1	8000	63	25	1	1.33	0.46	0.09	242	91.2

/TABLE 5 .....

TABLE 5

Type of Aluminium Powder	Specific Surface cm^2/cm^3	K-Round Ballistics				
		r_b at 1000 p.s.i., inch/sec.	Pressure Exponent	Temperature Coefficient, %/deg.F.	Measured I_{sp}, lb.sec/lb.	I_{sp} Efficiency, %
NORAL 120/D atomized	3500	0.57	0.56	0.14	242	93.4
REYNOLDS 400 "	13,500	0.55	0.56	0.09	240	92.7
Flake	24,000	0.67	0.46	0.12	241	93.0
Atomized/flake 50/50	15,700	0.67	0.50	0.10	240	92.7

/The .....

The aluminium particle size has no effect on the measured performance figures which lie within ± 1 I_{sp} unit of the overall mean, which is within the experimental error in measuring I_{sp} in K rounds. In calculating the efficiency, the small amount of stearic acid on the flake aluminium has been neglected.

The aluminium particle size has a far greater effect on burning rate, pressure and temperature dependence. The finer atomized powder reduces the temperature coefficient of burning rate, whilst the flake powder increases burning rate and reduces pressure, and temperature, dependence.

6. BALLISTIC RESULTS FOR SLOWER BURNING ALUMINIZED PROPELLANTS CONTAINING AMMONIUM PICRATE

6.1 Propellants Containing 10, 20 and 30 per cent Ammonium Picrate

The range of 'higher burning rate' propellants described in Section 5 has been extended to lower burning rates by the replacement of part of the oxidizer with ammonium picrate. The propellant containing 30 per cent picrate and 15 per cent aluminium has a burning rate of 0.172 inch/sec. at 1000 p.s.i.

The ballistics of the ammonium-picrate-cooled, aluminized propellants are presented in Table 6 (p. 12).

Figure 6 illustrates the effect of increasing aluminium content (at the three picrate levels) on specific impulse and combustion efficiency. From these graphs it is possible to interpolate the optimum performance composition for any burning rate requirement in the range 0.17 to 0.475 inch/sec. at 1000 p.s.i.

The addition of aluminium at each of the picrate levels causes a maximum increase in performance of about 2 per cent; but the optimum aluminium concentration is much lower than that predicted from theoretical considerations (i.e., the OMOX compositions). The thrust efficiency drops rapidly as the aluminium content increases and the matrix energy decreases.

The actual measured performance of these propellants is much greater than that of non-aluminized propellants of similar burning rate (Figure 8). These latter compositions must contain an anti-resonance additive (such as 1 per cent titanium dioxide) which increases the burning rate; the atomized aluminium powder reduces burning rate and acts as a burning stabiliser. Thus, for a given burning rate requirement, the non-aluminized propellant with titanium dioxide must contain more ammonium picrate, i.e., for a burning rate of 0.25 inch/sec. at 1000 p.s.i. the non-aluminized propellant would deliver only 209 lb.sec/lb. impulse, whilst a 15 per cent aluminized one would deliver 230 lb.sec/lb.

The pressure and temperature dependence of burning of these propellants are generally lower than those of non-aluminized propellants of corresponding burning rate; as the aluminium content increases, so the pressure exponent decreases, though the temperature coefficients appear little affected.

6.2 Effect of Aluminium Particle Size

The advantageous effect of flake aluminium on the pressure dependence of burning rate of propellants not containing ammonium picrate has been described in Section 5.4. Table 7 (p. 13) compares the effect of atomized and flake aluminium powders on the burning rate, pressure dependence, and measured impulse of a series of picrate cooled propellants. The binder content was increased to 12 per cent in order to incorporate 15 per cent flake aluminium.

/TABLE 6 .....

TABLE 6

Composition No.	NH_4ClO_4, %	Ammonium Picrate, %	Al, %	K-round Ballistics				
				r_b at 1000 p.s.i., inch/sec.	Pressure Exponent	Temperature Coefficient, %/deg.F.	I_{sp} at 1000 p.s.i.	I_{sp} Efficiency, %
E.3230	79	10	-	0.49	0.63	0.20	233	95.8
E.3682	75	10	4	0.475	0.65	0.22	236.5	94.3
E.3683	71	10	8	0.430	0.64	0.21	239	93.5
E.3684	64	10	15	0.375	0.62	0.24	238	90.7
E.3685	57	10	22	0.313	0.52	0.20	233	88.2
E.3686	69	20	-	0.375	0.54	0.18	227	95.4
E.3677	64	20	5	0.310	0.61	0.21	229	93.5
E.3687	57	20	12	0.270	0.56	0.21	231.5	90.9
E.3688	51	20	18	0.213	0.40	0.16	229	88.0
E.3689	59	30	-	0.279	0.52	0.21	214.5	94.3
E.3690	54	30	5	0.237	0.65	0.18	218	92.0
E.3691	51	30	8	0.193	0.52	0.17	218.5	90.3
E.3692	44	30	15	0.172	0.43	0.20	210	83.3

All compositions contain 10 per cent binder and 1 per cent S.101 surface active agent.

/TABLE 7 .....

TABLE 7

Composition, %	E.3499	E.3500	E.3501	E.3502	E.3500	E.3501	E.3502
Ammonium perchlorate	59	59	59	59	59	59	59
Ammonium picrate	28	23	18	13	23	18	13
Aluminium: atomized	-	5	10	15	-	-	-
" : flake	-	-	-	-	5	10	15
S.101	1	1	1	1	1	1	1
Polyisobutene	12	12	12	12	12	12	12
K-Round Ballistics							
r_b at 1000 p.s.i., inch/sec.	0.258	0.242	0.249	0.255	0.326	0.373	0.45
Pressure exponent	0.47	0.58	0.64	0.66	0.48	0.45	0.45
I_{sp} lb.sec/lb.	210	223	229	234	223	227.5	230

Because of the tendency of cool aluminized propellants, such as E.3500, to block up a relatively small nozzle throat with an alumina slag, all the K-rounds in this series were fired in tandem (i.e., two rounds joined together and fired through the same nozzle of twice the throat area required for a single round).

The results in Table 7 indicate three interesting facts:

(i) By keeping the oxidizer content constant at 59 per cent it was demonstrated that the atomized aluminium has almost the same rate-reducing effect as ammonium picrate. However, the gain in measured performance at a burning rate of 0.25 inch/sec. at 1000 p.s.i. is a full 10 per cent with 15 per cent aluminium.

(ii) The flake aluminium, which is at least ten times finer than the atomized material, does not improve the combustion efficiency.

(iii) The flake aluminium has an appreciable effect on burning rate and pressure dependence.

6.3 Propellants Containing Oxamide

A series of slow burning propellants (about 0.1 inch/sec. at 1000 p.s.i.) containing coarse oxidizer and both ammonium picrate and oxamide as coolants has been described in previous reports (1, 3). These propellants are characterised by a very low, and in some cases negative, pressure exponent at pressures between 1100 and 1800 p.s.i. Their advantages over the compositions containing only picrate as coolant are (i) considerably lower temperature coefficient of burning rate, in the region of the low pressure exponent, and

/(ii) .....

(ii) increased performance.

The disadvantages of these propellants are that slight changes in amount of oxidizer particle size breakdown (such as can arise during processing) cause considerable shift of the region of low pressure exponent, and there is a tendency to a high ignition pressure in rocket motor firings.

The addition of small amounts of aluminium has removed the 'plateau' burning characteristic and substituted a low pressure exponent (about 0.3) practically constant over the pressure range 300 - 1800 p.s.i., which is relatively insensitive to small changes on oxidizer particle size. A slight increase in measured performance has been noted. Small adjustments in burning rate can be made by varying the ratio of flake/atomized aluminium. Addition of larger amounts of aluminium to these cool compositions is impracticable because of nozzle blockage by a slag of oxide and unburnt aluminium.

Typical slow burning propellants of the type described are listed in Table 8.

TABLE 8

Composition, %	RD.2406	E.3592	E.3595	E.3593	E.3542/1	E.3542/2
Ammonium perchlorate	42	42	41	40	40	40
Ammonium picrate	41	39	39	38	38	38
Oxamide	5	5	5	5	5	5
Aluminium: atomized	-	-	1	-	5	2.5
" : flake	-	2	2	4	-	2.5
S.101	1	1	1	1	1	1
Polyisobutene	11	11	11	11	11	11
Burning Rates at:						
750 p.s.i.	0.099	0.116	-	0.138	0.105	0.131
1000 p.s.i.	0.111	0.130	0.125	0.150	0.119	0.144
1250 p.s.i.	0.113	0.138	-	0.162	0.127	-
1500 p.s.i.	0.102	0.147	0.145	0.199	0.136	0.162

/K-round .....

K-round performance figures for these compositions are not available but propellants R.D.2406 and E.3542 have been compared in the 30 KS 12,500 Raven motor. R.D.2406 gave a measured impulse of 188 lb.sec/lb. whilst the aluminized composition E.3542 gave 193 lb.sec/lb. Obviously the other compositions listed would give figures between 188 and 193 lb.sec/lb.

For rocket motor applications where a flashless exhaust is essential the aluminized compositions are not applicable.

7. SENSITIVENESS

All composite propellants are extremely sensitive to friction. Plastic propellants not containing ammonium picrate and with, or without, aluminium give 10 fires out of 10 in friction tests with a steel mallet on steel, naval brass or aluminium bronze; boxwood on York stone gives a similar result.

The replacement of oxidizer with ammonium picrate reduces the friction sensitiveness but, even in propellants containing as much as 60 per cent coolant, great care must be taken to avoid metallic friction during all stages of processing.

The Rotter impact test has been used to determine whether the addition of aluminium, or any other material, has had an appreciable effect on impact sensitiveness. Tests carried out early in the investigation indicated that the presence of aluminium had increased the impact sensitiveness slightly but to nothing like that of a non-aluminized propellant containing 1 per cent chromium sesquioxide burning rate additive. (See Table 9 - all compositions contain 10 per cent polyisobutene and 1 per cent S.101).

TABLE 9

Composition No.	NH_4ClO_4, %	Aluminium, %	Catalyst, %	Impact R.M.H. (RDX = 80)
E.3090	89	-	-	56
E.3312	88	-	1 Cr_2O_3	27
E.3328	87	1 Flake	1 Cr_2O_3	28
E.3318	79	10 Flake	-	43
E.3317	74	15 Flake	-	44

The propellants E.3318 and E.3317 had such poor rheological properties that further comparisons were made with compositions containing 12 per cent binder (Table 10).

/TABLE 10 .....

TABLE 10

Composition No.	NH_4ClO_4, %	Aluminium, %	Catalyst %	Impact R.M.H.
E.3283	87	-	-	91
E.3348/1	77	10, Flake	-	66
E.3348/2	77	10, Atomised	-	75
E.3364	77	10, Flake	1, Copper Chromate	52
E.3349	67	20, Flake	-	65

These results confirm that impact sensitiveness is increased by the presence of aluminium, a decrease in particle size of the aluminium, and the presence of a burning rate catalyst.

8. CONCLUSIONS

8.1 Propellant Ballistics

The addition of aluminium to plastic propellants has resulted in a marked improvement in measured performance over the whole range of burning rates 0.1 to 1.65 inch/sec at 1000 p.s.i. Figures 7 and 9 summarise the effect of aluminium on burning rate and specific impulse at the various ammonium picrate levels investigated.

The increase in performance is particularly noticeable in comparison with older type propellants (2) which contain ammonium picrate and titanium dioxide; the picrate being present to cool the propellant down to a particular burning rate, whilst the titanium dioxide, which acts as a burning rate catalyst, is necessary as an anti-resonance additive. Atomized aluminium acts in the dual role of coolant and anti-resonance additive, and also improves measured performance. A direct comparison of measured performance against burning rate of non-aluminized (but containing titanium dioxide anti-resonance additive) with aluminized propellants is given in Figure 8. The non-aluminized propellants are those in current use: the quoted specific impulse of the aluminized propellants at any particular rate represents the maximum measured in K-rounds during this investigation.

In comparison with current aluminized polyester polyurethane propellants and aluminized double-base propellants containing ammonium perchlorate, the aluminized plastic propellants described in this report have an equal or superior performance at any particular burning rate. In addition, their available burning rate range is at present greater than those of the polyurethane and double-base systems combined.

It is recommended, however, that the application of aluminized plastic propellants be restricted to those with burning rates above 0.25 inch/sec. at 1000 p.s.i. These propellants have shown a higher thrust efficiency and

/will .....

will be more reproducible in manufacture than the slower burning propellants containing oxamide, and/or large amounts of ammonium picrate.

8.2 Effect of Propellant Density on Rocket Motor Performance

The increased density brought about by the addition of aluminium has not been taken into account in the comparison in Figure 8. The relation between density and specific impulse of a propellant system and propulsive capability has been studied in detail by Aerojet-General (6) and Thiokol (7); in these treatments the effect of variations in density and specific impulse are discussed in terms of ideal boost velocity.

$$V_B = I_{sp}\, g.\, \log_e \left[1 + \rho\, V_p/M_i\right]$$

where V_B = boost velocity,

ρ = propellant density,

M_i = mass of inert parts.

V_p = volume of propellant.

The ideal boost velocity of the Gosling II motor is increased 17 per cent by replacing the current non-aluminized composition R.D.2304G (density 0.0607 lb/inch^3, measured specific impulse 216 lb.sec/lb.) with the aluminized composition E.3600 (density 0.065 lb/inch^3, specific impulse 245 lb.sec/lb.). [The Gosling II motor has a propellant volume factor of 51 inch^3 of propellant per lb mass of inert parts and the filled motor weight is 532 lb (propellant R.D.2304G) of which the tube and venturi weigh 130 lb.]

8.3 Thrust Efficiency of Aluminized Propellants

Factors influencing the thrust efficiency of aluminized propellants will be discussed more fully in another report; however, the current work has demonstrated that the efficiency is affected by the following parameters:

(a) matrix energy,

(b) propellant burning rate,

(c) rocket motor size.

The plastic propellants of high matrix energy (above 860 cal/g. of propellant) are all fast burning (above 0.4 inch/sec. at 1000 p.s.i.) and give high thrust efficiency (at least 94 per cent) irrespective of motor size.

Lower burning rates are achieved by reducing matrix energy by the replacement of oxidizer by coolant such as ammonium picrate - such propellants have lower thrust efficiencies which may be improved in larger rocket motors or by taking the artificial step of increasing the burning rate.

/8.4 .....

8.4 Sensitiveness and Processing

The addition of aluminium to plastic propellant has presented no additional hazard or new manufacturing problem; existing equipment at E.R.D.E., R.P.E. and R.O.F., Bridgwater is adequate for all foreseeable requirements.

9. ACKNOWLEDGEMENTS

Thanks are due to Dr. G.H.S. Young for helpful discussions on all aspects of the work.

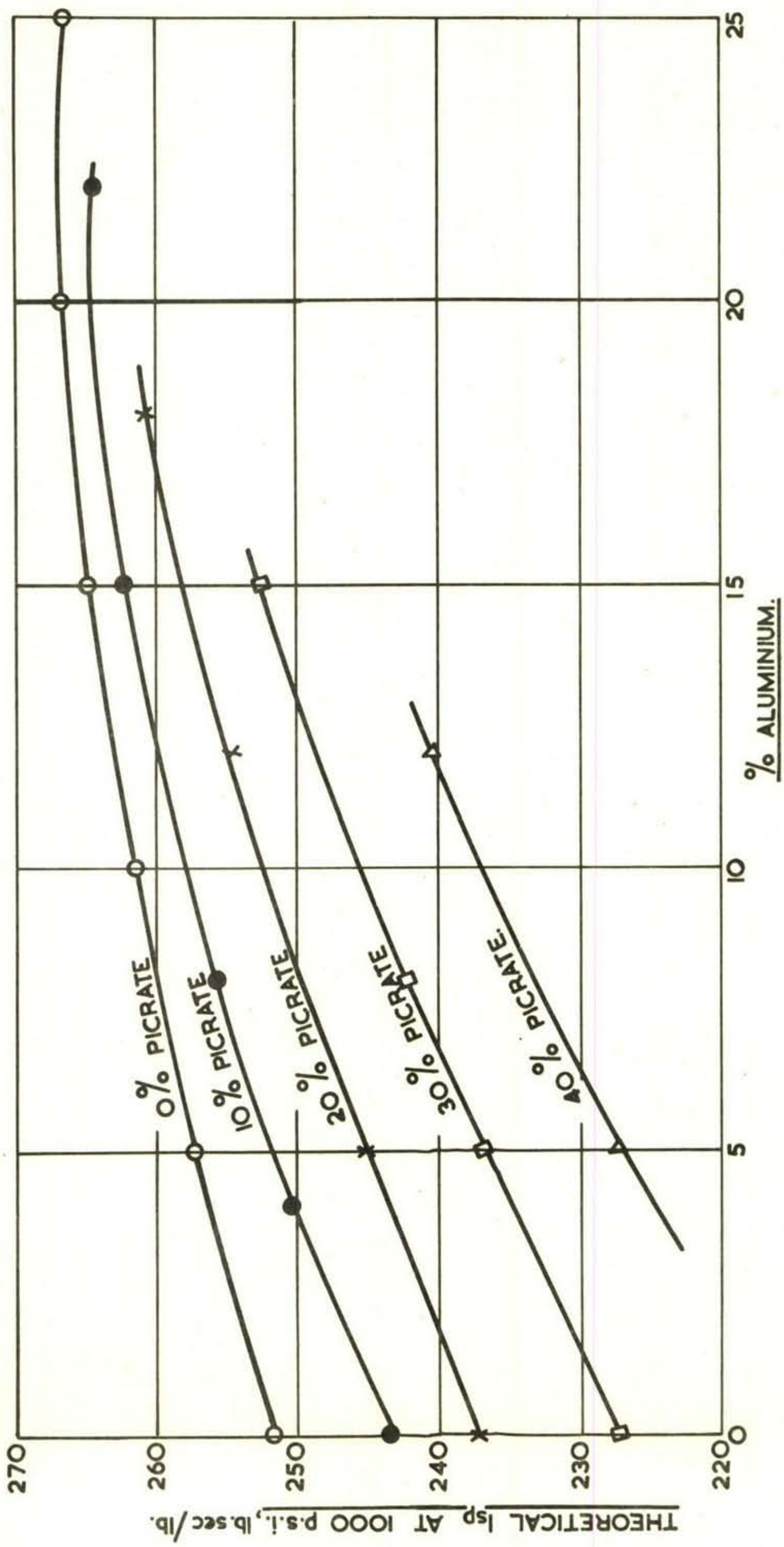
The specific impulse calculations were carried out under the supervision of Dr. J.A. Hicks and Mr. M.J. Harper.

The sensitivity tests were carried out by the Sensitiveness Section and the ballistic assessment by the South Site Proofstand.

10. BIBLIOGRAPHY

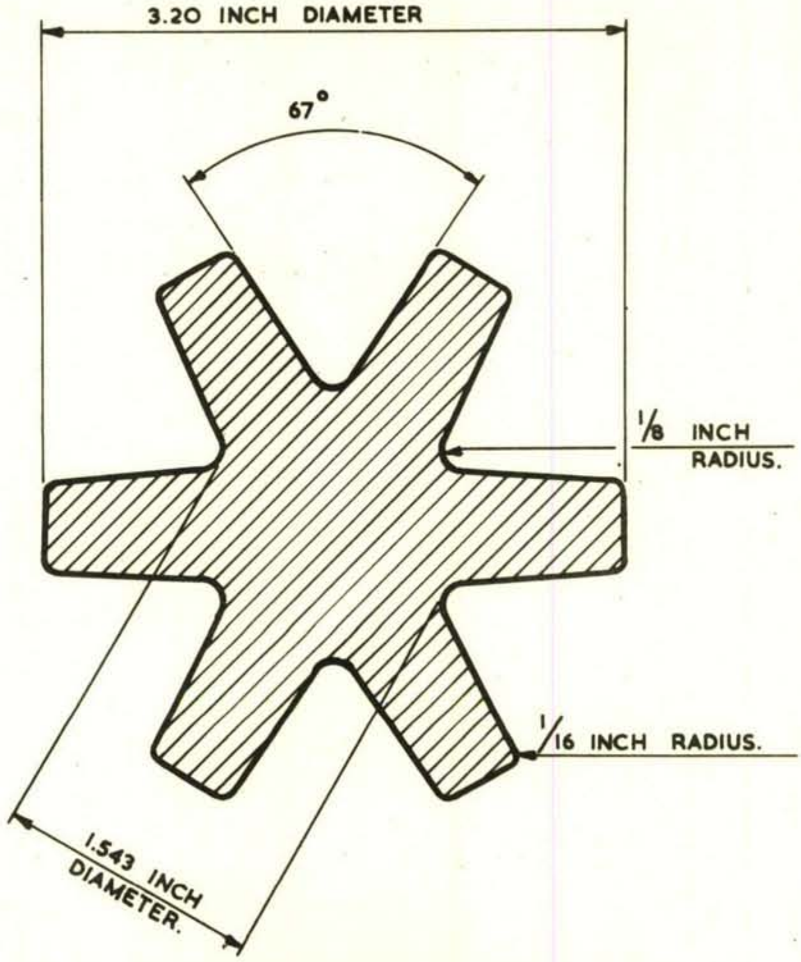
1. Newman, B.H., E.R.D.E. Report No. 14/R/59
2. Idem., E.R.D.E. Report No. 3/R/57
3. Newman, B.H., and Young, G.H.S., 15th J.A.N.A.F. Solid Propellant Meeting, Vol. IV, 1959
4. Newman, B.H., and Peers, C.H., E.R.D.E. Report No. 27/R/60
5. Harbert, B.C., and Keller, J.A., 15th J.A.N.A.F. Solid Propellant Meeting, Vol. IV, 1959
6. Lou, R.L., Aerojet General Final Report No. 1403, Vol. II Appendix E.
7. Thiokol, Quarterly Progress Report No. 18 - 60.

S. No. 735/60/JMK

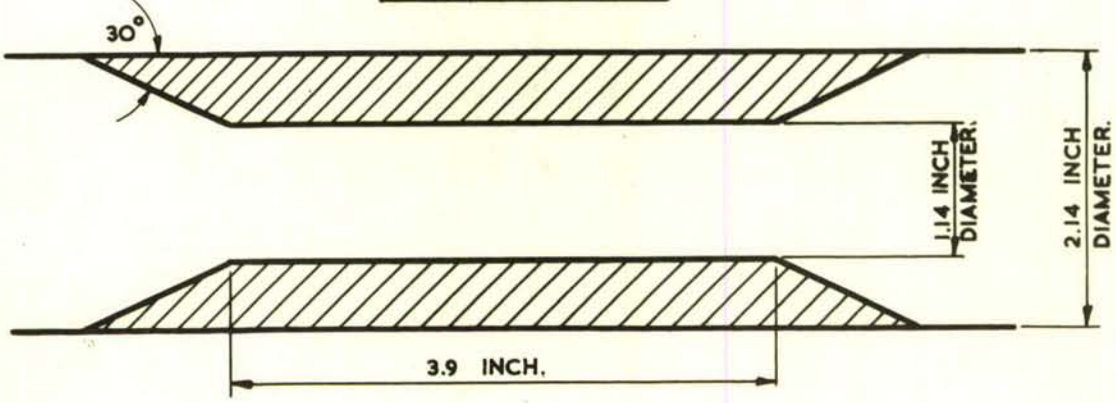


VARIATION OF THEORETICAL SPECIFIC IMPULSE WITH ALUMINIUM CONTENT. FIG. 1.

CONFIDENTIAL / DISCREET

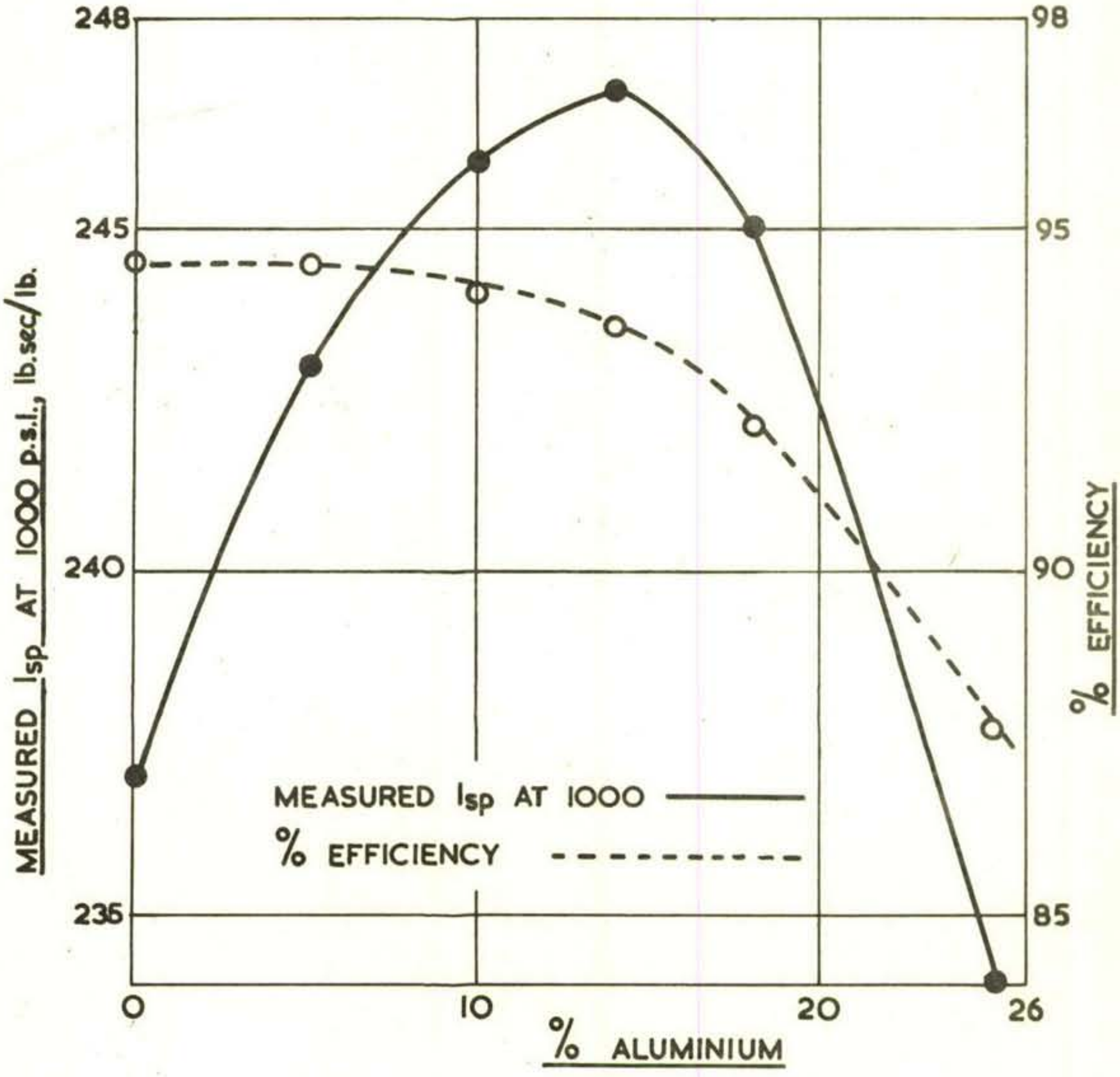


CROSS-SECTION OF CONDUIT OF 5-INCH DIAMETER MOTOR.



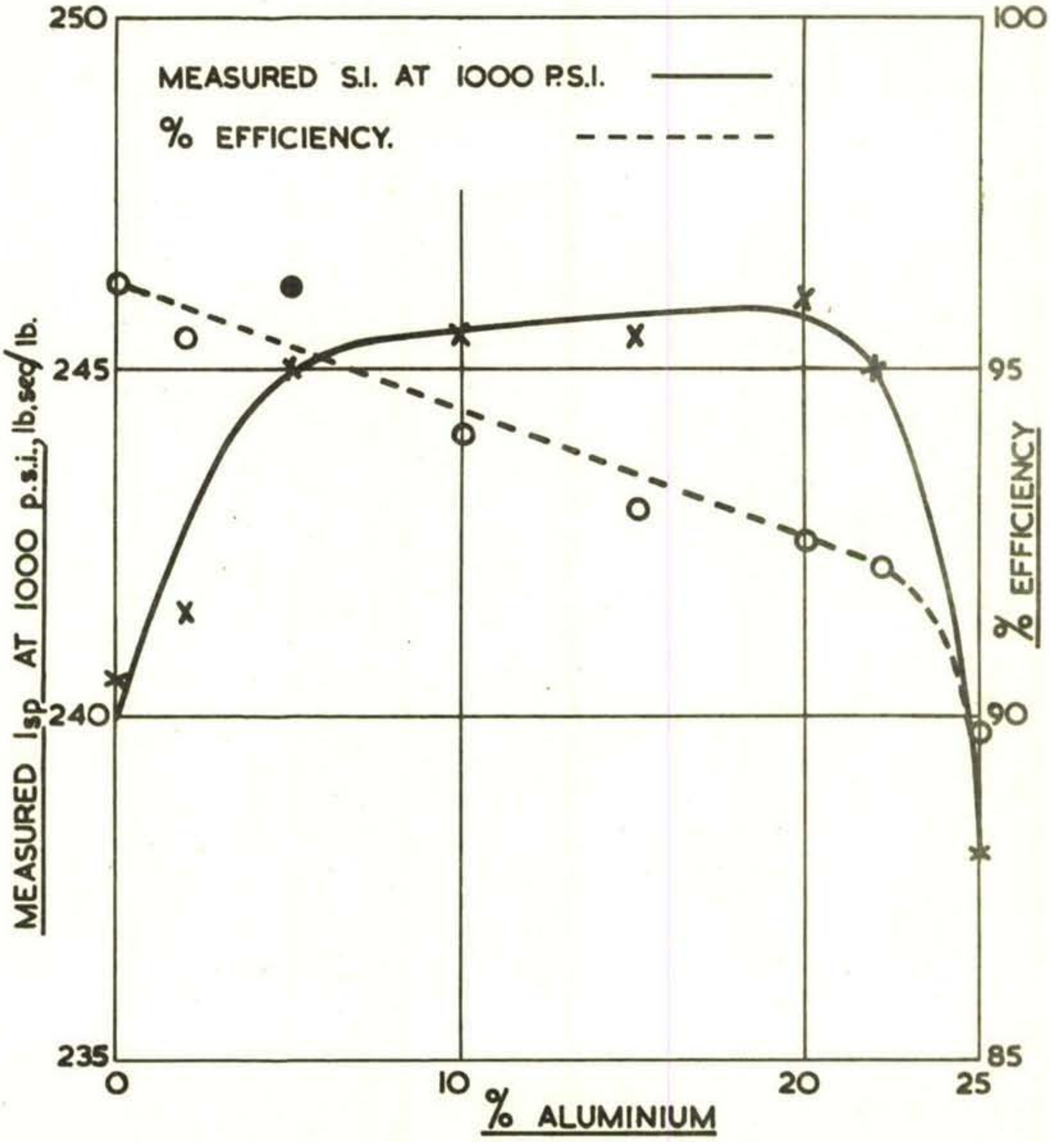
LONGITUDINAL CROSS-SECTION OF K-ROUND.

FIG. 2.



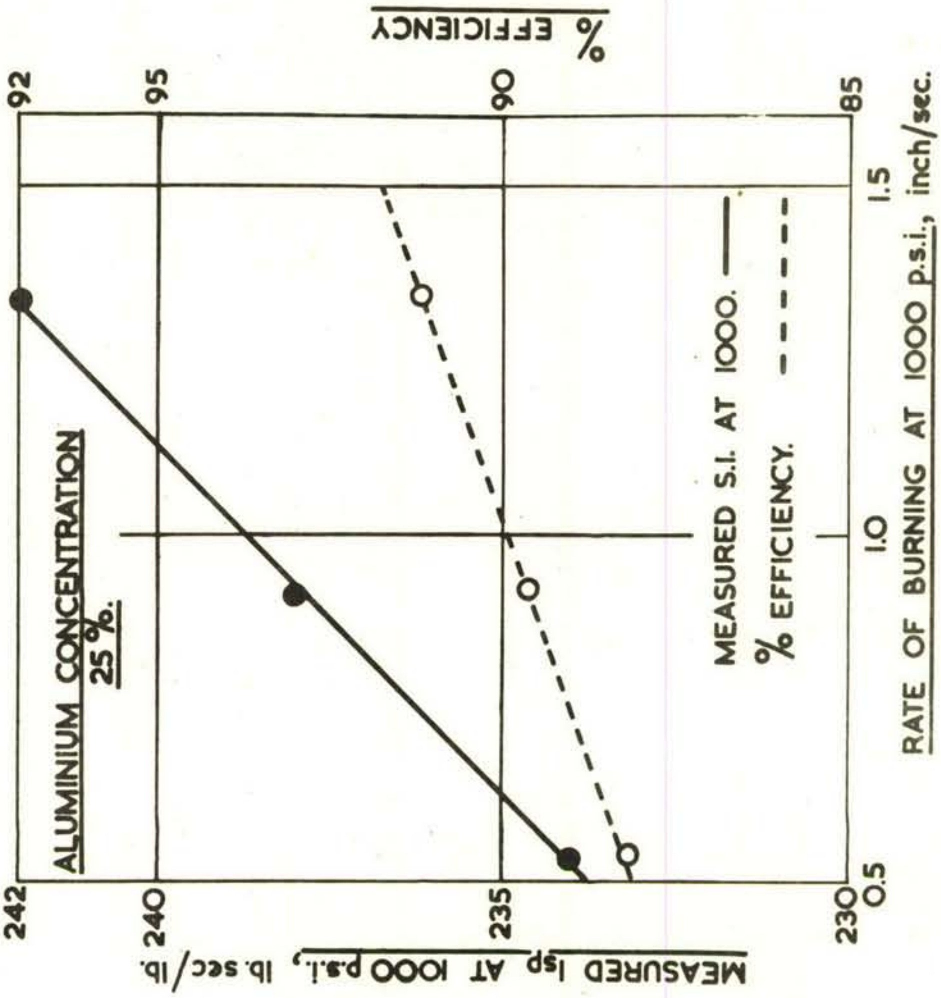
EFFECT OF ALUMINIUM CONCENTRATION ON MEASURED I_{sp} AT 1000 P.S.I. AND EFFICIENCY.

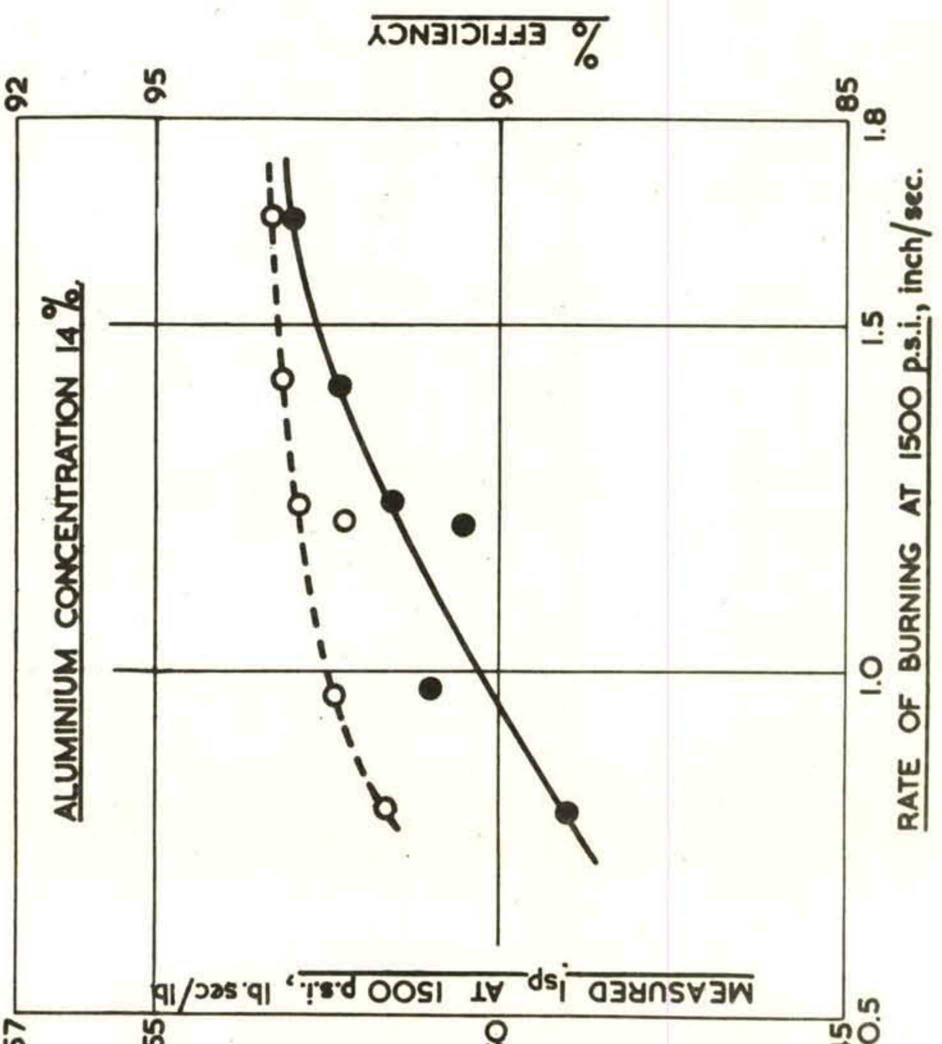
FIG. 3.



EFFECT OF ALUMINIUM CONCENTRATION ON MEASURED I_{sp} AT 1000 P.S.I. AND EFFICIENCY IN COMPOSITIONS CONTAINING 1% COPPER CHROMATE. FIG. 4.

CONFIDENTIAL/DISCREET



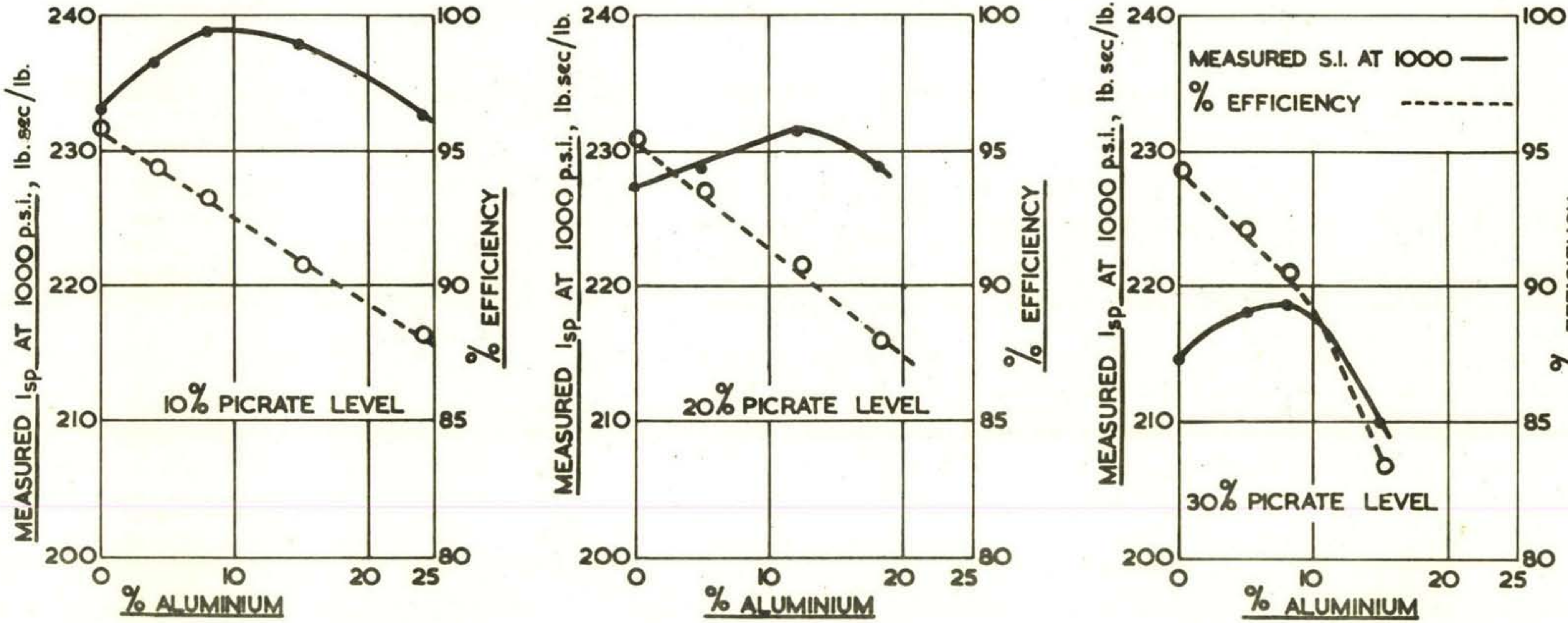


VARIATION OF I_{sp} AND EFFICIENCY WITH PROPELLANT BURNING RATE.

FIG. 5.

CONFIDENTIAL/DISCREET

CONFIDENTIAL / DISCREET



EFFECT OF ALUMINIUM CONCENTRATION ON MEASURED I_{sp} AT 1000 P.S.I. AND EFFICIENCY: 10% 20% AND 30% AMMONIUM PICRATE LEVELS. FIG. 6.

CONFIDENTIAL / DISCREET

CONFIDENTIAL / DISCREET

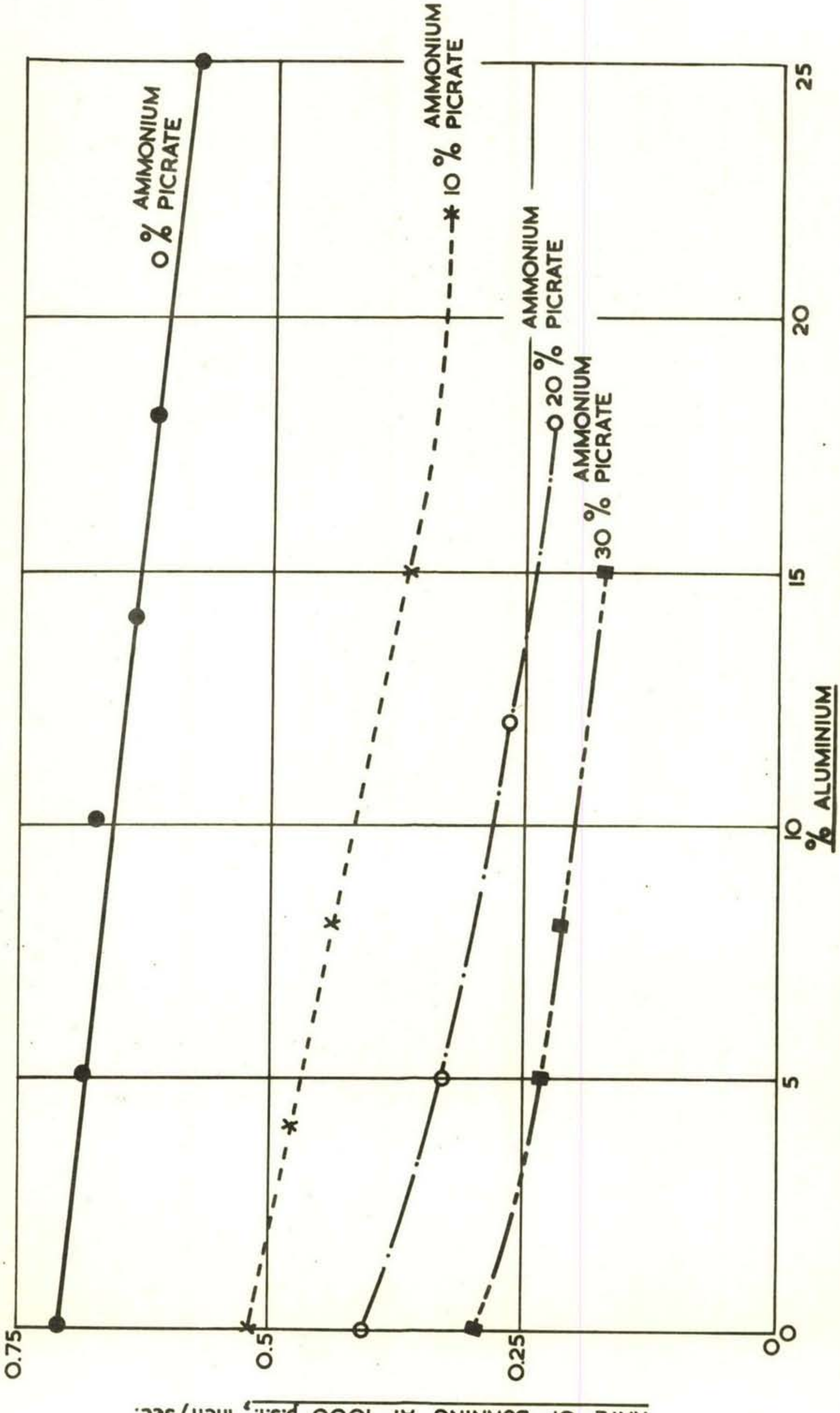


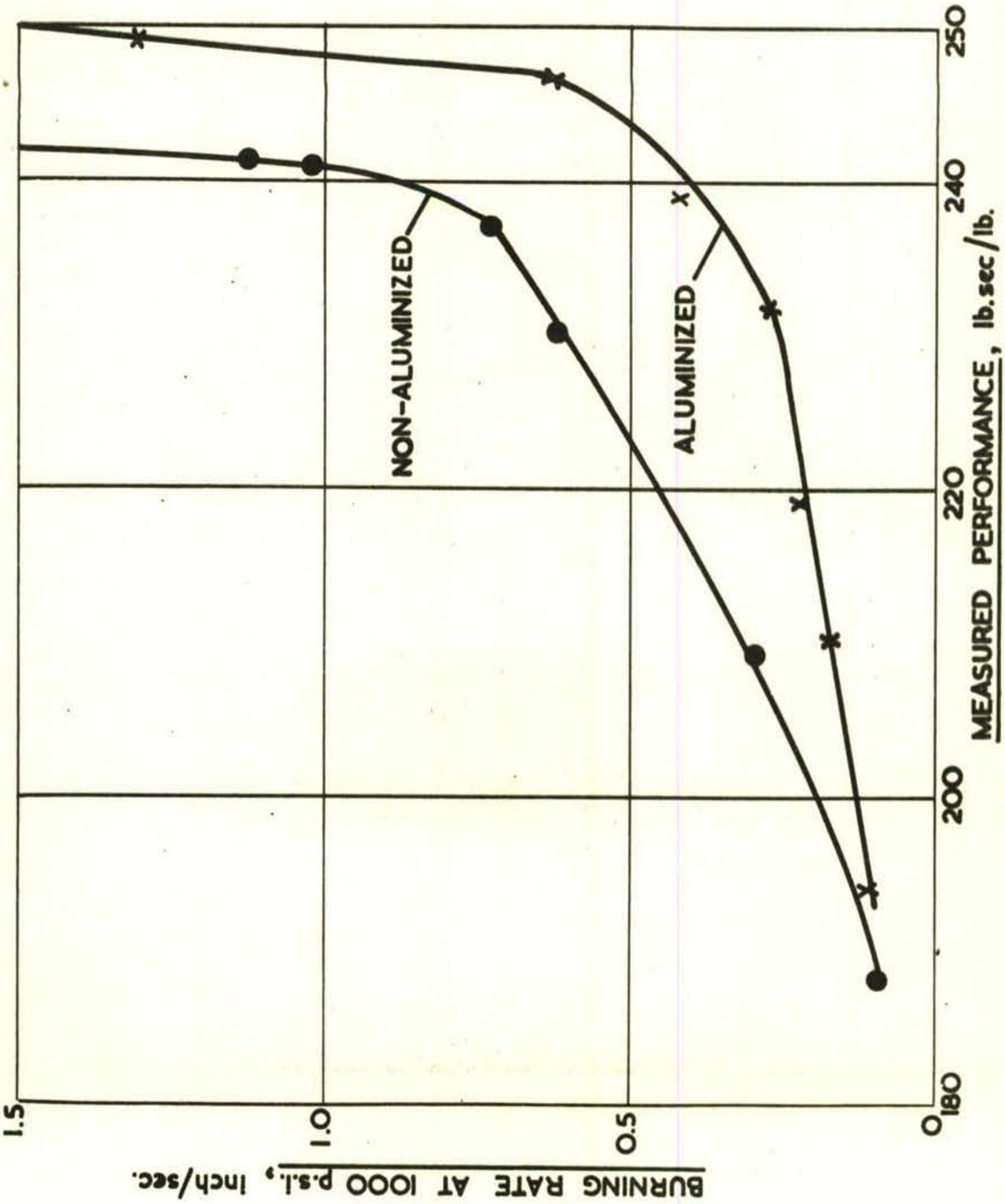
FIG. 7.

VARIATION OF BURNING RATE WITH ALUMINIUM CONTENT.

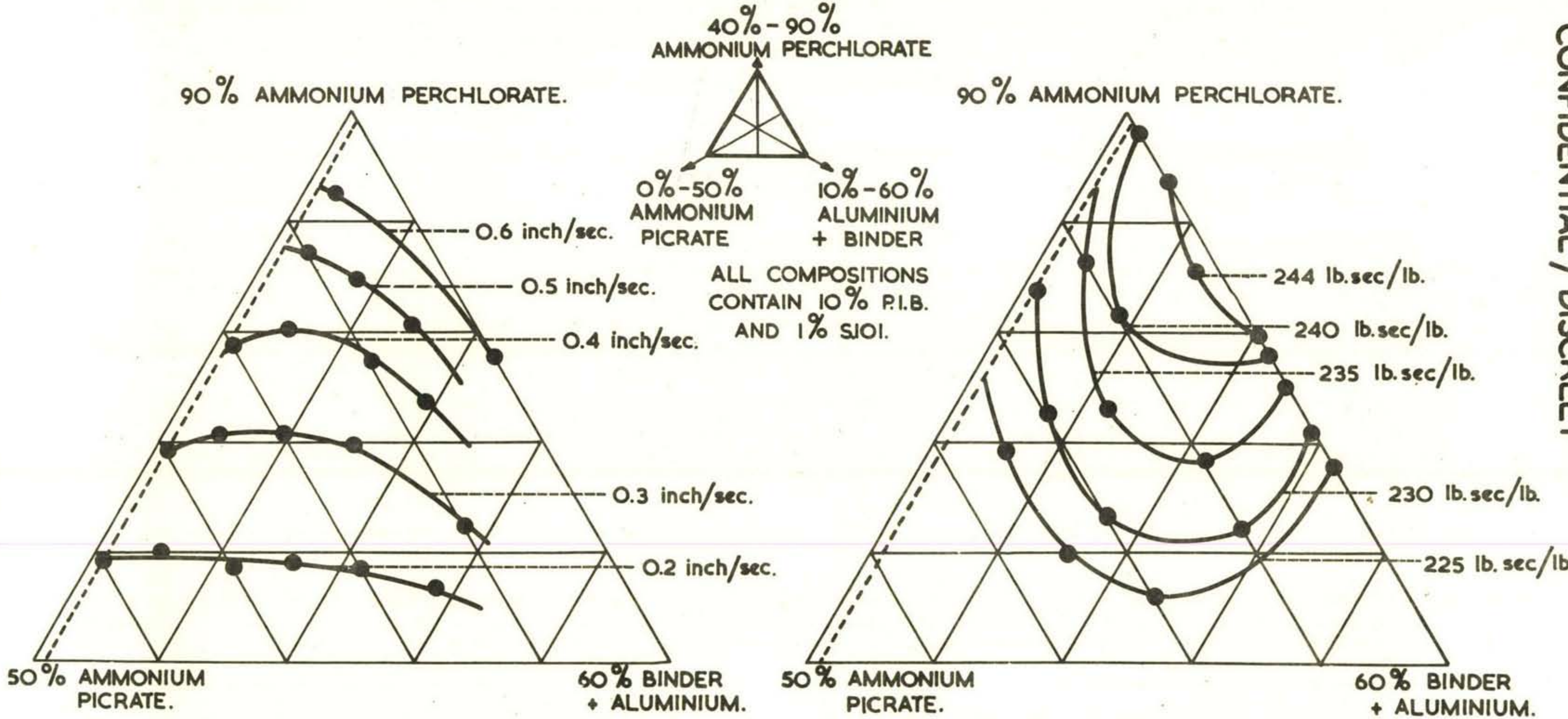
CONFIDENTIAL / DISCREET

COMPARISON OF MEASURED I_{sp} AND BURNING RATE AT 1000 p.s.i. FOR ALUMINIZED AND NON-ALUMINIZED COMPOSITIONS.

FIG. 8.



CONFIDENTIAL / DISCREET



TRIANGULAR PLOT SHOWING COMPOSITIONS WITH THE SAME BURNING RATES AT 1000 p.s.i.

TRIANGULAR PLOT SHOWING COMPOSITIONS WITH THE SAME MEASURED I_{sp} AT 1000 p.s.i.

FIG. 9.

~~CONFIDENTIAL/DISCREET~~

E.R.D.E. Report No. 8/R/61

Plastic Propellants: Aluminized Compositions

B.H. Newman and G.J. Spickernell June, 1961

The addition of aluminium to plastic propellants has resulted in a marked improvement in performance over the whole range of burning rates, 0.1 to 1.65 inch/sec. (at 1000 p.s.i.). In particular, high measured specific impulses (at least 245 lb.sec/lb) and high thrust efficiencies have been obtained with propellants burning at rates above 0.6 inch/sec. at 1000 p.s.i. and containing up to 18 per cent aluminium. Lower burning rates have been achieved by replacing oxidizer by ammonium picrate, but this was accompanied by a reduction in measured impulse and thrust efficiency.

The thrust efficiency of aluminized propellants is influenced by the three parameters: matrix energy (the energy of the binder/oxidizer part of the propellant), the propellant burning rate and the rocket motor size. The thrust efficiency of the fast-burning, high-matric-energy propellant, is probably unaffected by motor size until more than 20 per cent aluminium is present. The aluminium particle size has no effect on combustion efficiency although it affects burning rate, pressure dependence and temperature coefficient of burning rate.

/The .....

18 pp., 9 fig., 10 tables

~~CONFIDENTIAL/DISCREET~~

~~CONFIDENTIAL/DISCREET~~

E.R.D.E. Report No. 8/R/61

Plastic Propellants: Aluminized Compositions

B.H. Newman and G.J. Spickernell June, 1961

The addition of aluminium to plastic propellants has resulted in a marked improvement in performance over the whole range of burning rates, 0.1 to 1.65 inch/sec. (at 1000 p.s.i.). In particular, high measured specific impulses (at least 245 lb.sec/lb) and high thrust efficiencies have been obtained with propellants burning at rates above 0.6 inch/sec. at 1000 p.s.i. and containing up to 18 per cent aluminium. Lower burning rates have been achieved by replacing oxidizer by ammonium picrate, but this was accompanied by a reduction in measured impulse and thrust efficiency.

The thrust efficiency of aluminized propellants is influenced by the three parameters: matrix energy (the energy of the binder/oxidizer part of the propellant), the propellant burning rate and the rocket motor size. The thrust efficiency of the fast-burning, high-matrix-energy propellant, is probably unaffected by motor size until more than 20 per cent aluminium is present. The aluminium particle size has no effect on combustion efficiency although it affects burning rate, pressure dependence and temperature coefficient of burning rate.

/The .....

18 pp., 9 fig., 10 tables

~~CONFIDENTIAL/DISCREET~~

UNCLASSIFIED

~~CONFIDENTIAL/DISCREET~~

The addition of aluminium to plastic propellant has presented no additional hazard or new manufacturing problem, and the chemical stability has been unaffected.

~~CONFIDENTIAL/DISCREET~~

~~CONFIDENTIAL/DISCREET~~

The addition of aluminium to plastic propellant has presented no additional hazard or new manufacturing problem, and the chemical stability has been unaffected.

~~CONFIDENTIAL/DISCREET~~

UNCLASSIFIED

DETACHABLE ABSTRACT CARDS

The Abstract Cards detached from this document are located as follows:

8" x 5"

1. Section .... Signature .... Date ....

2. Section .... Signature .... Date ....

5" x 3"

1. Section .... Signature .... Date ....

2. Section .... Signature .... Date ....

3. Section .... Signature .... Date ....

4. Section .... Signature .... Date ....

~~CONFIDENTIAL~~
~~DISCREET~~
UNCLASSIFIED

UNCLASSIFIED

~~CONFIDENTIAL~~
~~DISCREET~~